012-05921A
12/95
$1.00

**Instruction Sheet
for the PASCO
Model ME-8949**

EQUAL ARM BALANCE

Introduction

The PASCO Model ME-8949 Equal Arm Balance was designed to be used in a vertical position to compare weights hung vertically from it to standard weights. This balance can also be used in a horizontal (or vertical) position to show that torques about its axis of rotation must be of the same magnitude if it is to remain in an equilibrium position. The Balance can be used with hanging weights or with applied forces measured with spring scales.

Equipment

The ME-8949 Equal Arm Balance consists of a symmetric molded plastic arm attached to a low friction, freely rotating brass axle. Masses can be suspended from the grooves on top of the plastic arm or from the loops on the bottom of the arm. If an outer loop or groove is used, a mass difference of about 2% between the two ends of the balance is detectable.

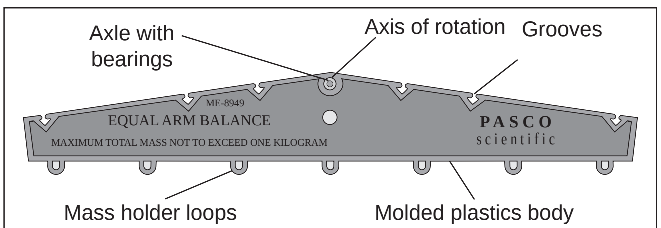

Figure 1: Equal Arm Balance

Additional Equipment Required:

Use a Base and Support Rod (ME-9451), or a Universal Table Clamp (ME-9376B) rod for basic support. Then use a Right Angle Clamp (SE-9444) or Multi-Clamp (SE-9442) to attach the Equal Arm Balance to the support rod.

For vertical observations with hanging masses:

– 2 SE-8703 Slotted Mass Hangers with SE-8726 Slotted Mass Set and/or
– 1 ME-9348 Mass and Hanger Set and/or
– 2 SE-8705 Hooked Mass Sets

For horizontal observations with applied forces:

– 2 SE-8716 5N Metric Spring Scales or
– 2 SE-8715 2N Metric Spring Scale or
– 2 SE-8714 1N Metric Spring Scale

Theory

The vector sum of torques with respect to the axis of rotation of an object must be zero if the object is to remain in a state of rotational equilibrium. If a force is applied to the Equal Arm Balance at one of the grooves or loops the torque exerted on the Balance can be calculated.

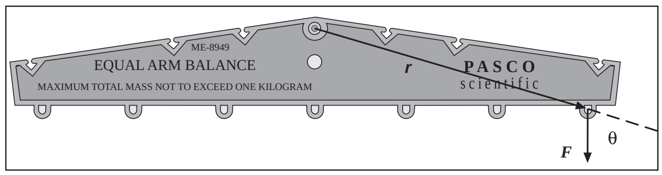

Figure 2: Calculating Force

The magnitude of the torque, τ, is given by the product of the magnitude of the moment arm vector, r and the force vector, F and the sine of the angle between the extension of the moment arm and the line along which the force vector acts. Thus,

$$\tau = rF \sin\theta$$

Torque is actually a vector. Its direction can be found from the moment arm and force by using a right hand rule. The moment arm is defined as the vector pointing from the axis of rotation to the point of action of the force. Lay the fingers of the right hand along $\vec{r}$. Your thumb will point perpendicular to the plane containing vectors $\vec{F}$ and $\vec{r}$. Curl your fingers toward $\vec{F}$. The direction your fingers curl is the direction of the torque.

Written by Priscilla Laws. Based on Units 5, 12, and 13 of the Workshop Physics Activity Guide. Published by John Wiley and Sons (1996). Permission was granted by the publisher for these adaptations .

PASCO® scientific
10101 Foothills Blvd. • P.O. Box 619011 • Roseville, CA 95678-9011 USA
Phone (916) 786-3800 • FAX (916) 786-8905 • email: techsupp@PASCO.com

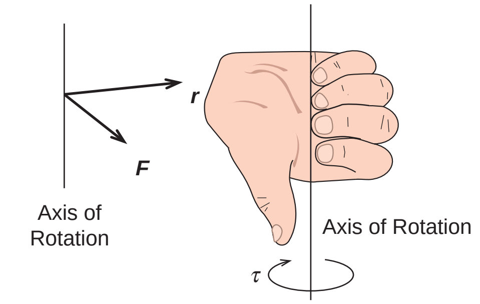

Fig 3: Using Right Hand Rule to Find Direction of Torque

Suppose the balance is mounted vertically. A standard mass can be hung vertically from a groove or loop on one side of the balance. An object of unknown mass can be hung from a groove or loop at the same distance on the other side of the Balance. If the balance doesn't rotate then the masses are equal. This is because the net torque caused by the gravitational forces on one side of the balance is equal in magnitude and opposite in direction to the net torque caused by the gravitational forces on the other side of the balance. Thus, the Equal Arm Balance can be used to determine a gravitational mass by comparison with a standard mass. It can also be used to explore the concept of torque as a vector quantity.

Setup

Vertical Setup

① Set up a base and support rod and attach a right angle clamp to the support rod.

② Attach the Balance axle to the right angle clamp so that the plane of the Balance is vertical.

③ For use as an Equal Arm Balance hang masses from loops at equal distances from the axis of rotation. Alternatively, hang masses with light string or wire loops attached to them on each side of the center of the Balance using the upper grooves.

> ➤**NOTE** For testing the torques that result from gravitational forces, hang a standard mass from one of the grooves or loops on one arm of the Balance. Place another mass at a groove or loop on the opposite side of the Balance that is a different distance from the center. How much more or less mass is needed to achieve a balance? What is the torque on each side of the balance.

Horizontal Setup

① Set up a base or table clamp and support rod and attach a multi-clamp to the top of the support rod.

② Attach the Balance axle to the multi-clamp so that the plane of the Balance is horizontal.

> ➤**NOTE** For testing the torques that result from applied forces, pull with a steady force on one of the loops on one arm of the Balance. For simplicity, pull in a direction that is in the same plane as the balance but is perpendicular to the bottom edge of the Balance. Exert another force at loop on the opposite side of the balance. This force should still be in the same horizontal plane as the Balance, but it can be at a different distance from the center or in a different direction. How much more or less force is needed to balance that standard torque? Can you calculate the magnitude and direction of the torque on each side of the balance?

> ➤ **CAUTION:** The total mass hanging from the Balance should never exceed one kilogram and the net pulling force on the Balance should never exceed 10 N.

Suggested Experiments

This experiment has been adapted from Unit 5: One Dimensional Forces, Mass, and Motion

What is mass?

Philosophers of science are known to have great debates about the definition of mass. If we assume that mass refers somehow to "amount of stuff", then we can develop an operational definition of mass for matter that is made up of particles that appear to be identical. We can assume that mass adds up and that two identical particles when combined have twice the mass of one particle; three particles have three times the mass; and so on. But suppose we have two objects that have different shapes and are made of different stuff, such as a small lead pellet and a silver coin. How can we tell if these two entities have the same mass?

Ideas about Mass and Its Measurement

① Attempt to define *mass* in your own words without using the word "stuff".

② How many different ways can you think of to determine whether a lead pellet and a silver coin have the same mass?

③ Suppose you find that the lead pellet and the silver coin seem to have the same mass. How could you create "stuff" that has twice the mass of either of the original objects?

Using a Mass Balance

One time honored way that people have used to compare the mass of two objects is to put them on a balance. If they happen to balance each other we say that the "force of gravity" or the force of attraction exerted on them by the earth is the same, so they must have the same mass.

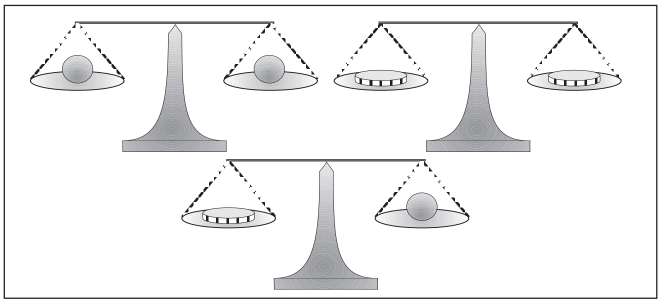

Fig. 4: **A common method of determining mass that assumes two objects have the same mass if they experience the same gravitational force.**

Using a Balance to Measure an Arbitrary Mass

① Explain how you might measure the passive gravitational mass of an object using the balance, sand, and standard coin.

② Use the Equal Arm Balance with some masses of different sizes and shapes to test your ideas.

This experiment has been adapted from Unit 12: Rotational Motion

The Rotational Analog of Force – What Should It Be?

If linear equilibrium results when the vector sum of the forces on an object is zero (i.e. there is no *change* in the motion of the center of mass of the object), we would like to demand that the sum of some new set of rotational quantities on a stationary non-rotating object also be zero. By making some careful observations you should be able to figure out how to define a new quantity which is analogous to force when it comes to causing or preventing rotation. For this set of observations you will need:

- 1 Equal Arm Balance
- 1 clamp stand (to hold the Balance)
- 2 spring scales, 5 N
- 1 ruler

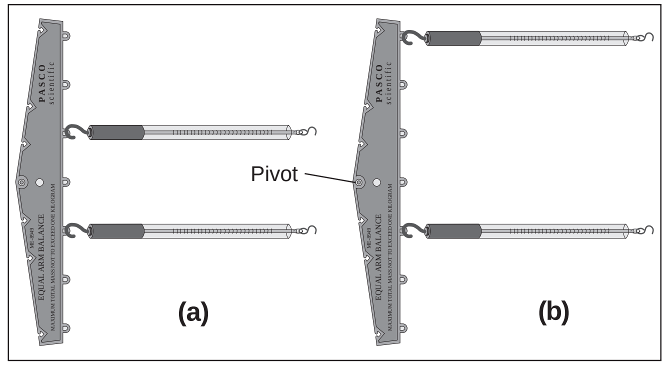

Fig. 5: Equal Arm Balance & Spring Balances

Force and Lever Arm Combinations

① Rotate the Equal Arm Balance horizontally on the pivot. Try pulling horizontally with each scale when they are hooked on loops that are the same distance from the pivot as shown in Figure 5, diagram (a) above. What ratio of forces is needed to keep the Balance from rotating around the pivot?

② Try moving one of the spring scales to some other loop as shown in Figure 5, diagram (b). Now what ratio of forces is needed to keep the Balance from rotating? How do these ratios relate to the distances? Try this for several different situations and record your results in Table 1 below.

Table 1

	Original Force (N)	Original Distance (cm)	Balancing Force (N)	Balancing Distance (cm)
1				
2				
3				
4				

③ What mathematical relationship between the original force and distance and the balancing force and distance give a constant for both cases? How would you define the rotational factor mathematically? Cite evidence for your conclusion.

④ Show quantitatively that your original and final rotational factors are the same within the limits of experimental uncertainty for *all four* of the situations you set up.

The rotational factor that you just discovered is officially known as *torque* and is usually denoted by the Greek letter τ ("tau" which rhymes with "cow"). The distance from the pivot to the point of application of a force is defined as the *lever arm* for that force.

This experiment has been adapted from Unit 13: Angular Momentum and Torque as Vectors

Observation of Torque when $\vec{F}$ and $\vec{r}$ are not Perpendicular

In Experiment 2, you "discovered" that if we define torque as the product of a lever arm and perpendicular force, an object does not rotate when the sum of the torques acting on it add up to zero. However, we didn't consider cases where $\vec{F}$ and $\vec{r}$ are not perpendicular, and we didn't figure out a way to tell the direction of the rotation resulting from a torque. Let's consider these complications by generating torques with spring balances and an Equal Arm Balance once more. For this activity you'll need:

- 1 Equal Arm Balance
- 1 clamp stand (to hold the Balance)
- 2 spring scales, 5 N
- 1 ruler
- 1 protractor

Torque as a Function of Angle

① Suppose you were to hold one of the scales at an angle of 90° with respect to the lever arm, r_h, and pull on it with a steady force. Meanwhile you can pull on the other scale at several angles other than 90° from its lever arm, r_{app}, as shown below. Would the magnitude of the balancing force be less than, greater than, or equal to the force needed at 90°? What do you predict? Explain.

② You should determine *exactly* how the forces compare to that needed at a 90° angle. Determine this force for at least *four different angles* and *figure out a mathematical relationship between F, r, and θ. Set up a spreadsheet to do the calculations shown in Table2 below* . **Hint**: Should you multiply the product of the measured values of r and F by sinθ or by cosθ to get a torque that is equal in magnitude to the holding torque?

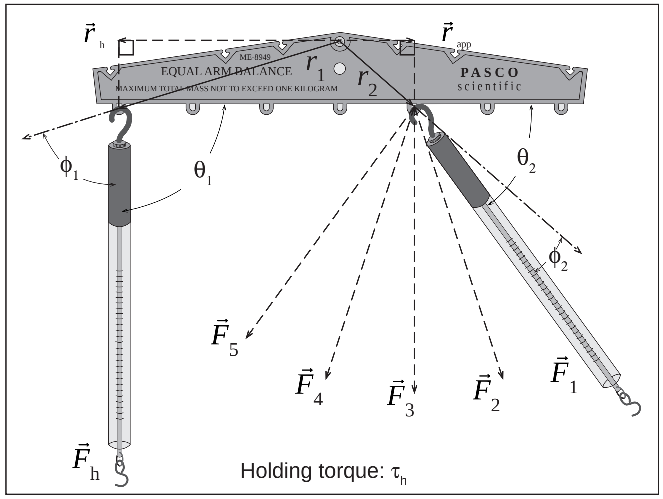

Fig 5: Torque at an angle

③ Within the limits of uncertainty, what is the most plausible mathematical relationship between τ and $\vec{r}$, $\vec{F}$, and θ?

Limited Warranty

PASCO scientific warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment, after repair, will be paid by PASCO scientific.

Table 2

Holding Torque			Applied Torque							
r_h(m)	F_h(N)	τ_h(Nm)	r_{app}(m)	F_{app}(N)	θ(deg)	θ(rad)	cosθ	sinθ	$r_{app}F_{app}\cos\theta$	$r_{app}F_{app}\sin\theta$